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Regeneration in Mixed Conifer and Douglas-Fir Shelterwood Cuttings in the Cascade Range of Washington

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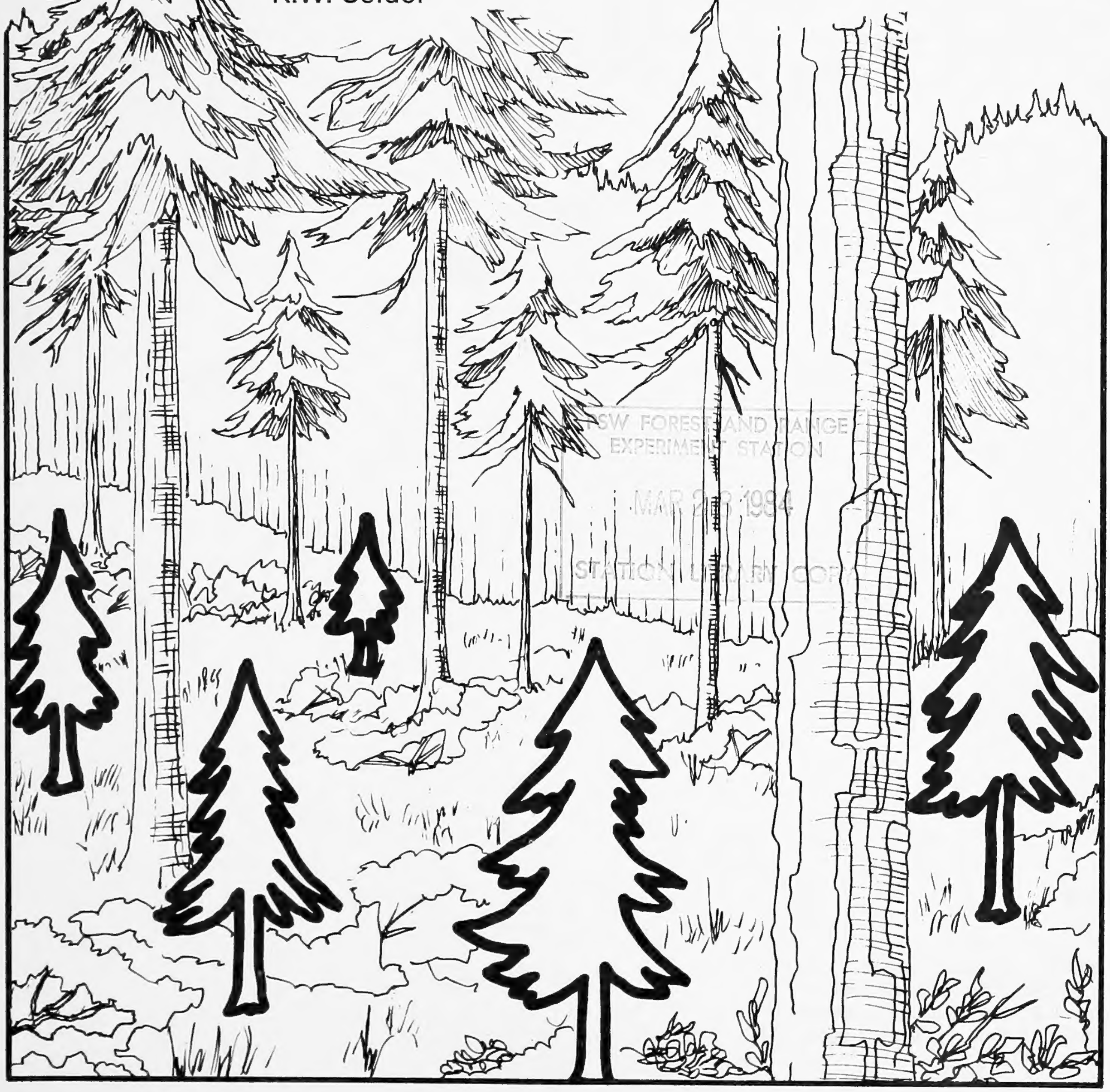

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Abstract

Seidel, K. W. Regeneration in mixed conifer and Douglas-fir shelterwood cuttings in the Cascade Range of Washington. Res. Pap. PNW-314. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1983.** 17 p.

A survey of shelterwood cuttings in mixed conifer and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) forests in the Cascade Range in Washington showed that, on the average, shelterwood units were adequately stocked with a mixture of advance, natural postharvest, and planted reproduction of a number of species. Shelterwood cuttings in the Douglas-fir type had abundant regeneration, whereas those in the mixed conifer type had generally adequate stocking but fewer seedlings. Much of the understocking appeared to be related to a nonuniform overstory, lack of advance reproduction, or high elevation.

Keywords: Shelterwood cutting method, regeneration (stand), regeneration (natural), regeneration (artificial), Cascade Range—Washington, Washington (Cascade Range).

Summary

Regeneration of shelterwood cuttings in mixed conifer and Douglas-fir forests at midelevation of the Cascade Range in Washington was surveyed for an overview of the status of reforestation and to identify key environmental factors influencing establishment of seedlings. Plots were randomly located in shelterwood units harvested from 1970 to 1976 in a Douglas-fir and a mixed conifer forest type in the Cascade Range.

On the average, shelterwood units in the mixed conifer type were stocked with about 1,572 seedlings or saplings per acre (all origins), whereas the Douglas-fir units contained an abundance of regeneration (7,111 per acre). Average milacre stocking of mixed conifer was 56 percent; of Douglas-fir, 89 percent. About 73 percent of the reproduction in the mixed conifer type and 96 percent in the Douglas-fir type were of natural postharvest origin. Planted seedlings accounted for less than 10 percent of the regeneration in both types but were present on a greater number of stocked milacres than their small numbers might suggest because of their uniform distribution.

Greater stocking was generally associated with increasing density of the overstory. Other factors, such as aspect, slope, and elevation, varied in their relationship to stocking depending on species and forest type. Understocking in the mixed conifer type appeared to be related to a nonuniform overstory, lack of advance reproduction, or high elevation. Equations for predicting stocking were derived for several species in both types, but, because of the large amount of unexplained variation, they serve only as crude estimates of possible stocking.

Usually, residual stand density after the seed cut should be reduced to the minimum level at which an acceptable amount of regeneration will be established. It appears that 6 to 8 trees per acre in the Douglas-fir type and about 25 trees per acre in the mixed conifer type distributed uniformly over the area should result in adequate stocking on most units.

Planting is generally unnecessary after the seed cut in the Douglas-fir type because of prolific natural regeneration. In the mixed conifer type, planting is needed if residual stand density is much below 25 trees per acre or where aggressive understory vegetation could quickly occupy the seedbed. Blowdown of the residual overstory was greater in the mixed conifer type—about 1.3 trees per acre compared with 0.5 tree in the Douglas-fir type. The risk of blowdown can be reduced by leaving trees that are fully crowned dominants or codominants (the most windfirm and also the best producers of seed) and by locating cutting boundaries where the risk of windthrow is low.

Introduction

The shelterwood method was used to harvest timber in many upper slope mixed conifer forests in eastern Oregon and Washington during the late 1960's and 1970's. This method was a way of modifying the harsh environmental conditions found on many high elevation clearcuts that cause regeneration to fail. Some of these shelterwood units are now old enough for regeneration to be established, but success has varied considerably—from units well stocked with a number of species to units with very little regeneration.

The presence of these units in various plant communities provided an opportunity to evaluate the regeneration and to relate various environmental factors to its establishment. This paper reports the results of a 1981 field survey of regeneration on two Ranger Districts in the Wenatchee and Gifford Pinchot National Forests, the factors affecting its establishment, and survival of the residual overstory.

Objectives

The purposes of this study were to: (1) quantitatively evaluate regeneration on the shelterwood units, (2) determine survival of residual overstories during the regeneration period, and (3) identify environmental factors associated with the presence or absence of regeneration.

Specific objectives were to estimate:

1. Success of regeneration in terms of stocking percentage and density (number per acre).
2. Species composition of the regeneration.
3. Stocking of regeneration of preharvest (advance) and postharvest (natural and planted) origins.
4. The relationship between regeneration and some measurable environmental variables, such as elevation, aspect, slope, and overstory density.
5. Survival of the residual overstories.

Study Areas

Study areas were located in the Cascade Range of Washington (fig. 1). A plant community classification has not been completed for this area. Therefore, plots were located in two forest cover types based on overstory tree species. These two types are: (1) The Douglas-fir type where Douglas-fir is the primary species (Mount Adams District of the Gifford Pinchot National Forest) and (2) the mixed conifer type where no single overstory species was dominant (Naches District of the Wenatchee National Forest).[1]

The major tree species found in these types are Douglas-fir, grand fir, western hemlock, mountain hemlock, and western larch. The understory vegetation is generally well developed, and many species are present. Primary species in the mixed conifer type are bearberry, prince's pine, big huckleberry, common snowberry, shinyleaf spirea, pinegrass, Idaho fescue, sky lupine, twinflower, woollyweed, rattlesnake plantain, and American vetch.

Principal understory species in the Douglas-fir type are vine maple, thimbleberry, baldhip rose, big huckleberry, boxwood, and beargrass.

Soils supporting the mixed conifer forest type are Cryorthents and Cryandepts (Snyder and Wade 1973). Cryorthents are generally very deep soils (12 feet or more) underlain by igneous or pyroclastic bedrock. These soils are derived from glacial till and are generally well drained; they have a sandy loam texture. Cryandepts are somewhat shallower soils (1 to 10 feet) derived from residuum or colluvium. Surface soils are sandy loams or loams, and subsoils vary from gravelly loams to silty clays. Both soil types are considerably influenced by volcanic ash or loess. Soils in the Douglas-fir type are similar. They generally range from 2 to more than 12 feet in depth and are derived from till, colluvium, and residuum with local areas of ash, cinders, and pumice. Texture of the surface soil varies from coarse sand to loamy sand.

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[1] Scientific names of plants are listed on page 11.

Some characteristics of the shelterwoods sampled are given in table 1. The average elevation of mixed conifer plots was about 1,500 feet higher than elevation of the Douglas-fir plots (4,525 vs. 3,079 feet). The major difference in the overstory between the two types was species composition and tree size. On the average, plots in the Douglas-fir type contained fewer but larger trees and more basal area than plots in the mixed conifer type.

In the Douglas-fir type, the primary overstory species was Douglas-fir, comprising 65 percent of the trees (fig. 2). Other species present were grand fir—10 percent, western hemlock—6 percent, mountain hemlock—6 percent, Engelmann spruce—4 percent, Pacific silver fir—5 percent, plus small numbers of western redcedar and western larch.

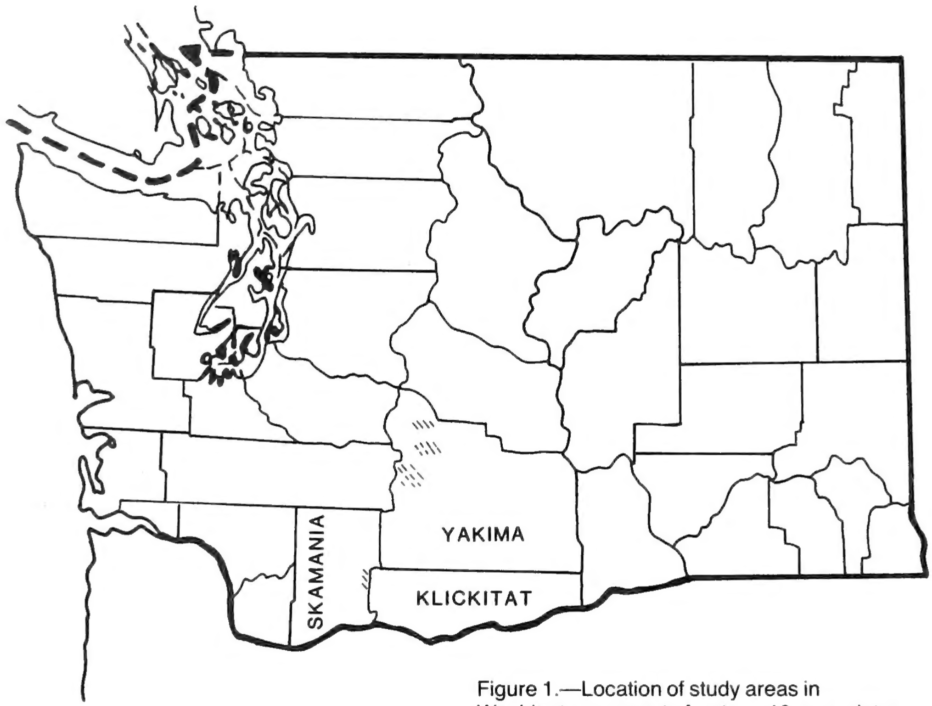

Figure 1.—Location of study areas in Washington; seven to fourteen 10-acre plots were sampled in each of the four areas.

Table 1—Mean and range of some characteristics of shelterwood units sampled in 2 timber types in the Cascade Range of Washington

Characteristic	Unit of measure	Douglas-fir type (14 plots)		Mixed conifer type (26 plots)	
		Mean	Range	Mean	Range
Elevation	Feet	3,079	2,750-3,750	4,526	3,000-5,300
Slope	Percent	5.5	0-19	7.5	0-18
Age	Years	7.2	4-10	5.9	5-11
Residual overstory:					
Trees per acre	Number	15.4	9-27	19.4	9-32
Average diameter	Inches	33.5	27-41	20.4	12-29
Basal area	Square feet	66.1	25-114	38.3	18-57
Crown closure	Percent	37.7	17-57	26.0	11-35
Seedbed:					
Mineral soil	Percent	12.3	2-28	1/	1/
Litter	Percent	52.3	36-67	1/	1/
Slash	Percent	14.9	6-32	14.9	7-30
Understory vegetation:					
Forbs	Percent	13.7	2-34	10.0	1-32
Shrubs	Percent	24.4	1-69	7.2	0-30
Grasses and sedges	Percent	10.2	0-69	19.8	2-40

1/ Values not given because of errors caused by ash deposits on some plots from eruption of Mount St. Helens.

Methods

Figure 2.—Shelterwood unit in the Douglas-fir type.

Mixed conifer plots exhibited greater diversity of species, and no single species dominated the overstory. Grand fir and Douglas-fir each accounted for about 23 percent of the overstory; western larch and mountain hemlock each comprised 16 percent. Other species were Engelmann spruce—9 percent, ponderosa pine—6 percent, and western hemlock—3 percent. Pacific silver fir, western redcedar, lodgepole pine, and western white pine were also present but only in small numbers, each amounting to less than 1 percent of the overstory.

Slash on all plots in the Douglas-fir type was piled by machine and burned after the seed cut. In the mixed conifer type, slash was piled and burned on 23 of 26 plots; on 2 plots, unmerchantable material was yarded; on 1 plot, slash was not treated.

Survey Design and Plot Selection

Douglas-fir and mixed conifer types were considered separate populations. A record of shelterwood units harvested in 1976 or earlier in these timber types in east-side Ranger Districts of the Gifford Pinchot and Wenatchee National Forests was obtained from the USDA Forest Service Regional Office (Pacific Northwest Region) in Portland, Oregon. Only units at least 5 years old were considered suitable for sampling so that reproduction would have had time to become established. Plot size was 10 acres; thus, all shelterwood units of this size or larger and at least 5 years old were potential plots.

I estimated that a total of about 40 plots could be sampled during the available time. Therefore, 26 plots were selected at random from the total number (196) in the mixed conifer type and 14 from the total (65) in the Douglas-fir type, resulting in a sampling intensity of about 13 and 22 percent, respectively. Candidate sample plots were rejected if the shelterwood unit was direct seeded to trees or if it had been converted to nonforest uses.

Collection of Data

A grid of 25 sample points was centrally located on each 10-acre plot, spaced at 66-foot intervals. At each sample point, three concentric subplots (1-milacre, 4-milacre, and 0.0785-acre) were examined for presence of regeneration, associated environmental variables, and condition of residual overstory.

Ranger District records and field observations provided plot information on elevation, timber type, date of harvest, slash treatment method and year of treatment, species planted and year of planting, subsequent cultural treatments, and general notes on size, growth, and distribution of regeneration, or damage.

On each 1-milacre subplot, the total number of seedlings of each species was counted and recorded by origin—preharvest (advance) or postharvest (subsequent). Trees of postharvest origin were divided into 1- and 2-year-old seedlings from natural seed fall, seedlings 3 years old and older from natural seed fall, and planted trees. On each 4-milacre subplot, the species and origin (advance, natural postharvest, or planted) of the seedling or sapling most likely to dominate the subplot because of its size and vigor were recorded.[2] Four-milacre subplots were used for data on dominant trees to reduce the probability of unstocked subplots. On each 0.0785-acre subplot, species and diameter at breast height (d.b.h.) were recorded for overstory trees, including trees that died during the regeneration period, and windthrown trees.

Planted trees were identified from information on species planted, date of planting, and spacing. In shelterwoods where survival was high, regular rows of planted trees were clearly visible. Identification of planted trees was less certain when survival was low, but counting branch whorls to check the age of a tree helped to identify planted trees.

The following environmental factors associated with each 1-milacre subplot were observed and recorded:[3] aspect; slope; condition of the seedbed (mineral soil, litter, slash); degree of burn; understory vegetation (forbs, shrubs, grasses); residual overstory density (basal area and percent crown closure); and presence or absence of animal damage.

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[2] A dominant tree was selected on the basis of its height, general vigor as indicated by live crown ratio and past height growth, and species.

[3] See appendix for details of procedures of measuring and coding the environmental factors.

Results and Discussion

Analysis of Data

To illustrate the present status of reforestation, I summarized data in tables showing seedling numbers and stocking percentage of milacre subplots by species and origin for the forest types. To determine the relationship between regeneration and environmental variables, I used stepwise multiple regression procedures to fit linear equations of the form $Y = b_0 + b_1 X_1 + b_2 X_2 + \ldots b_n X_n$ to the data. Dependent (Y) variables used were percentages of milacre subplots stocked and number of seedlings per acre of the various species and origins, and the independent (X) variables were the environmental variables given in the appendix.[4] Curvilinear equations of the form $Y = a + b(1 - e^{-cx})^d$ were used to relate individual independent variables to percentage of stocked milacres because in some cases they described the relationship more realistically than did a linear model.

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[4] Subplots were considered stocked if they contained at least one seedling.

Regeneration Stocking and Density

Regeneration on shelterwood units in the mixed conifer type, for all species and origins combined, was generally satisfactory in terms of average seedling numbers and stocked milacres (1,572 per acre and 56 percent stocked) (table 2). The Douglas-fir shelterwood units contained an abundance of regeneration. Seedling density (all classes) averaged 7,111 per acre, and 89 percent of the milacre subplots were stocked.

The majority of the regeneration in both timber types consisted of seedlings of natural origin that became established after the seed cut. This was especially true in the Douglas-fir type where 96 percent of the regeneration was of natural postharvest origin compared with 73 percent in the mixed conifer type. Advance reproduction was a negligible component (less than 1 percent) of the regeneration in the Douglas-fir type, but in the mixed conifer type it accounted for about 19 percent. This difference can be attributed to the fact that there was little advance reproduction present before logging in the Douglas-fir shelterwoods and that nearly all of it was destroyed in the slash treatments that were applied uniformly over the units. In contrast, the residual overstory stocking was more irregular in the mixed conifer units, and distribution of advance reproduction was clumpy, occurring mostly in areas undisturbed by logging or slash treatment activity.

One- and two-year-old seedlings were generally present in considerable numbers, accounting for 40 percent of the reproduction in the Douglas-fir type and 26 percent in the mixed conifer type. In spite of their large numbers, these young seedlings do not play as great a role as other components of the regeneration because of their small size and high mortality rates. The primary effect of these seedlings was to increase density of the regeneration rather than to greatly increase stocking percentages. In the Douglas-fir type, for example, milacre stocking was increased more than 12 percent on only 7 percent of the plots even though the young seedlings made up 40 percent of the regeneration.

Table 2—Average stocking percent and number of seedlings per acre of all species on shelterwood units in 2 timber types in the Cascade Range of Washington, by class of reproduction [1]

Class of reproduction	Douglas-fir type			Mixed conifer type		
	Number of plots	Mean ± S.E. [2]	Range	Number of plots	Mean ± S.E. [2]	Range
			Stocking percent			
Advance	14	3.1 ± 0.9	0-12	26	13.5 ± 2.6	0-44
Postharvest:						
1- and 2-year-old seedlings	14	58.0 ± 6.8	16-96	26	19.5 ± 3.3	0-60
3-year-old and older seedlings	14	78.0 ± 3.6	52-96	26	30.0 ± 3.5	4-64
Planted seedlings	12	28.7 ± 5.6	0-56	21	14.7 ± 2.8	0-44
All classes except 1- and 2-year-old seedlings	14	83.7 ± 3.2	56-96	26	47.4 ± 2.4	12-76
All classes	14	89.1 ± 3.0	56-100	26	56.0 ± 3.9	24-88
			Number per acre			
Advance	14	37 ± 11	0-160	26	294.0 ± 70	0-1,520
Postharvest:						
1- and 2-year-old seedlings	14	2,840 ± 540	480-6,240	26	406.0 ± 82	40-1,480
3-year-old and older seedlings	14	4,003 ± 750	1,320-12,200	26	746.0 ± 136	40-3,280
Planted seedlings	12	270 ± 64	0-680	21	156.0 ± 31	0-480
All classes except 1- and 2-year-old seedlings	14	4,271 ± 737	1,400-12,280	26	1,166.0 ± 141	240-3,400
All classes	14	7,111 ± 954	3,960-15,500	26	1,572.0 ± 196	400-4,840

1/ Based on 1-milacre subplots.

2/ S.E. = standard error.

Planted seedlings made up only 4 to 9 percent of reproduction. Although present in small numbers, planted seedlings are distributed almost uniformly over units which results in a greater percentage of stocked milacres than might be expected by their small numbers (table 2).

Establishment of natural regeneration in these shelterwood units was both profuse and rapid after the seed cut. Even though the average age of these units is only 6 to 7 years, the largest single component of the regeneration is natural postharvest seedlings 3 years old and older (table 2). For seedlings of this age to be present, adequate seed must have fallen within 1 to 3 years after logging. Establishment of seedlings within a few years after the seed cut appears to be common not only in these forest types but also in mixed conifer forests in the Cascade Range and Blue Mountains in Oregon (Seidel 1979, Seidel and Head 1983).

For a greater insight into the levels of stocking and seedling density among the shelterwood units, plots were grouped according to the number and percentage that attained specific levels of stocking or density (table 3). The considerable difference in establishment of regeneration between the two timber types is apparent. If 40-percent stocking of milacre quadrats is considered satisfactory, then all the Douglas-fir units meet this standard compared with 69 percent of the mixed conifer units. Based on seedling numbers, all the Douglas-fir shelterwoods had at least 700 seedlings per acre in contrast to only 77 percent of the mixed conifer units. Lack of regeneration is not a problem on the Douglas-fir shelterwoods; rather, some of the units are overstocked. Five units had more than 7,000 seedlings per acre with a maximum density of 15,520 on one plot. Although large numbers of seedlings are present now, overstocking after the seed cut is not an immediate problem because some regeneration will be lost when the residual overstory is removed. Stocking level control should begin promptly after the final removal cut, however, in areas where regeneration is excessively dense.

Table 3—Proportion of shelterwood units stocked at various levels with 3-year-old and older advance and postharvest regeneration in 2 timber types in the Cascade Range of Washington 1/

Timber type	Stocking			Trees per acre		
	At least	Plots	Proportion of total	At least	Plots	Proportion of total
	Percent	Number	Percent	Number	Number	Percent
Douglas-fir (14 plots)	20	14	1.00	200	14	1.00
	40	14	1.00	400	14	1.00
	60	13	.93	700	14	1.00
	80	10	.71	1,000	14	1.00
	100	7	.50	2,000	12	.86
				3,000	9	.64
				5,000	4	.29
Mixed conifer (26 plots)	20	25	.96	200	26	1.00
	40	18	.69	400	24	.92
	60	10	.38	700	20	.77
	80	0	0	1,000	12	.46
				2,000	4	.15
				3,000	1	.04

1/ Based on 1-milacre subplots.

Species Composition of Regeneration

The mixture of species in the regeneration in both types was similar to that of the overstory. Douglas-fir and grand fir were the two most abundant species in the Douglas-fir type, found on 78 and 44 percent of the milacres, respectively (table 4). Stocking of the other nine species in the reproduction was much less, ranging from 0.3 percent for ponderosa pine to 8.6 percent for mountain hemlock.

In the mixed conifer type, grand fir and Douglas-fir were also the two major species, but stocking of the other species (except for western and mountain hemlocks) was greater and no single species was found on the majority of milacres. The most noticeable shift in species composition was fewer hemlock seedlings and greater numbers of western larch, ponderosa pine, and lodgepole pine than in the Douglas-fir type.

Dominant Species

In addition to estimates of the abundance and distribution of the regeneration, a classification of seedling vigor or size is desirable to give some idea of the species most likely to predominate as the stand develops. In both types, Douglas-fir and grand fir were the two dominant species, and regeneration of natural postharvest origin was dominant on the majority of the stocked subplots (table 5). Because of their greater height and uniform distribution over the units even though present in small numbers, planted seedlings (primarily Douglas-fir) were dominant on about one-third of the stocked subplots in the Douglas-fir type and on about one-fourth of the stocked subplots in the mixed conifer type.

It is evident from these data that, although Douglas-fir and grand fir were the two major species in the regeneration in both types, the mixed conifer type has more species occupying dominant positions in contrast to the Douglas-fir type where all species other than Douglas-fir and grand fir were dominant on 3 percent or less of the stocked subplots.

Table 4—Average stocking of advance and postharvest regeneration on shelterwood units in 2 timber types in the Cascade Range of Washington, by species 1/

Species	Douglas-fir type, postharvest seedlings 2/				Mixed conifer type, postharvest seedlings 2/			
	Advance seedlings	3-year-old and older	1- and 2-year-old	All classes	Advance seedlings	3-year-old and older	1- and 2-year-old	All classes
	Stocking percent ± S.E. 3/							
Grand fir	0.6 ± 0.4	38.9 ± 7.3	14.9 ± 4.5	44.3 ± 7.6	9.8 ± 2.3	15.4 ± 2.7	7.8 ± 1.6	29.5 ± 3.5
Pacific silver fir	.9 ± .5	1.7 ± 1.0	.6 ± .6	2.9 ± 1.6	1.1 ± .5	0 ± --	.3 ± .2	1.2 ± .5
Douglas-fir	.9 ± .6	70.3 ± 6.3	46.3 ± 8.3	78.0 ± 6.2	.5 ± .3	12.9 ± 3.0	8.9 ± 2.5	19.4 ± 3.8
Western hemlock	.6 ± .6	4.0 ± 1.9	7.8 ± 2.8	7.9 ± 2.9	.3 ± .3	.3 ± .2	.3 ± .3	.8 ± .6
Mountain hemlock	.6 ± .4	3.5 ± 1.3	8.4 ± 3.2	8.6 ± 3.3	.9 ± .5	2.5 ± 1.0	.8 ± .5	3.8 ± 1.4
Western redcedar	0 ± --	1.1 ± .7	0 ± --	1.1 ± .7	0 ± --	.3 ± .3	0 ± --	.3 ± .3
Engelmann spruce	0 ± --	5.4 ± 2.2	2.0 ± 1.2	5.7 ± 2.3	.3 ± .2	5.8 ± 1.6	1.2 ± .5	7.1 ± 1.8
Western white pine	0 ± --	3.4 ± 1.6	.3 ± .3	3.7 ± 1.6	0 ± --	2.5 ± .8	2.2 ± .9	4.6 ± 1.5
Western larch	0 ± --	2.9 ± 2.3	.3 ± .3	3.1 ± 2.3	.8 ± .3	6.9 ± 2.1	1.7 ± .9	8.6 ± 2.7
Ponderosa pine	0 ± --	.3 ± .3	0 ± --	.3 ± .3	.2 ± .2	3.8 ± 1.2	.8 ± .4	4.6 ± 1.6
Lodgepole pine	0 ± --	2.3 ± 1.2	0 ± --	2.3 ± 1.2	0 ± --	2.9 ± 1.6	1.1 ± .6	3.4 ± 1.7

1/ Based on 1-milacre subplots.

2/ Includes natural and planted regeneration.

3/ S.E. = standard error.

Table 5—Stocked subplots on shelterwood units, in 2 timber types in the Cascade Range of Washington, by species and origin of dominant seedlings 1/

Origin of seedlings	Grand fir	Pacific silver fir	Douglas-fir	Western hemlock	Mountain hemlock	Western redcedar	Engelmann spruce	Western white pine	Western larch	Ponderosa pine	Lodgepole pine	Total
	Percent											
Douglas-fir type:												
Advance	0.6	1.2	1.8	0.6	--	--	--	--	--	--	--	4.2
Natural postharvest	16.5	1.8	39.2	.6	1.8	--	1.2	0.6	1.5	0.3	--	63.5
Planted	7.9	--	23.8	--	--	--	.6	--	--	--	--	32.3
Total	25.0	3.0	64.8	1.2	1.8	--	1.8	.6	1.5	.3	--	100.0
Mixed conifer type:												
Advance	14.3	1.5	2.1	--	2.4	--	1.1	--	1.1	.6	0.2	23.3
Natural postharvest	14.3	.6	7.1	--	3.0	0.2	3.0	1.1	9.8	6.6	5.3	51.0
Planted	--	--	17.3	--	--	--	6.2	--	1.1	1.1	--	25.7
Total	28.6	2.1	26.5	--	5.4	.2	10.3	1.1	12.0	8.3	5.5	100.0

1/ Based on 4-milacre subplots; 1- and 2-year-old seedlings included.

Relation of Stocking and Density to Environmental Factors

For an assessment of the influence of observed environmental variables on density and stocking of regeneration and their relative importance, correlation coefficients were computed between each environmental variable and stocking percent and density of regeneration. The results of these analyses are presented in tables 6 and 7 in the appendix.

The effect of these variables on stocking and density of regeneration depends on the species as well as on the timber type. In the Douglas-fir type, for example, aspect showed a significant negative correlation to density of regeneration, indicating that regeneration was generally less abundant on more northerly aspects (table 7). Although significant, this relationship is based on plots' having a limited range of aspects and slopes, with some nearly flat. Regardless of aspect, however, regeneration was adequate on all plots. In the mixed conifer type, there was little relationship of aspect to stocking or density of regeneration.

Grass cover was negatively correlated to stocking and density of regeneration in the Douglas-fir type, but there was little relationship between grass and reproduction in the mixed conifer type (tables 6 and 7). Although a strong negative correlation exists between grass and regeneration in the Douglas-fir type, it appears that this is due to a single shelterwood unit with heavy grass cover and poor stocking; there is little relationship among the remaining units. Nevertheless, grass—especially sod-forming species—can offer severe competition to young seedlings (Dimock 1981). In both forest types, stocking of grand fir regeneration showed a significant positive correlation to woody understory vegetation (table 6) and to variables such as crown closure, basal area, or residual trees per acre which indicate a shadier microsite. This agrees with observations of many young grand fir seedlings growing under shrubs.

In general, the effect of these variables on stocking and density of regeneration in the Douglas-fir and mixed conifer types is summarized as follows:

Douglas-fir type

Increased stocking	Decreased stocking	Little relationship
More basal area	More northerly aspect	Elevation
More crown closure	Greater slope	Gopher damage
More overstory trees per acre	More grass	Burn
More litter	Animal damage	Forbs
	Greater age of unit	Shrubs
		Average diameter of overstory
		Mineral soil
		Slash

Mixed conifer type

Increased stocking	Decreased stocking	Little relationship
Greater crown closure	Higher elevation	Aspect
More overstory trees per acre	More forbs	Slope
Greater age of unit	Greater average diameter of the overstory	Slash
More shrubs		Burn
Animal damage		Grass
		Basal area
		Gopher damage

With few exceptions, most of the correlations appear reasonable. The positive correlation of animal damage to regeneration in the mixed conifer type was not expected, although a similar relationship was found in partial cuts in the Blue Mountains of northeastern Oregon (Seidel and Head 1983). Perhaps the additional disturbance of the seedbed by livestock and big game may have resulted in a more favorable seedbed; or consumption of grasses, forbs, and shrubs may have reduced competition from this understory vegetation. Although it is possible that increased numbers of seedlings could result from activity of livestock and big game, the net effect is likely to be negative because of damage to the regeneration that results in reduced height growth and poor form.

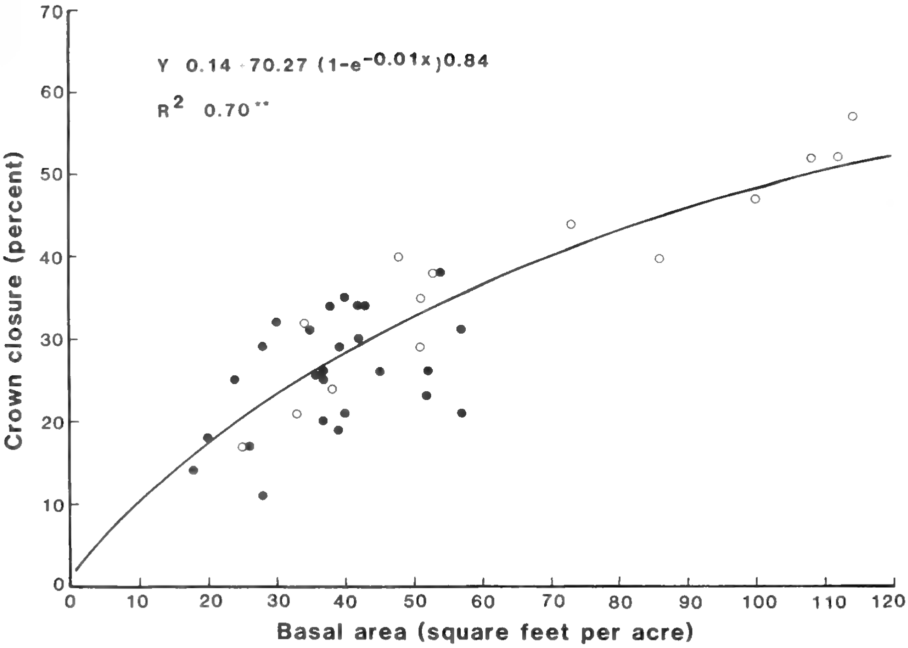

Figure 3.—Relationship between basal area and crown closure of residual overstory for all shelterwood plots in both Douglas-fir and mixed conifer types in the Cascade Range of Washington; ** means significant at the 1-percent probability level.

As expected, a good relationship was found between overstory crown closure and basal area ($R^2 = 0.7$) (fig. 3). The single curve fits the data from both forest types and is similar to the relationship for mixed conifer shelterwoods in the Cascades in Oregon (Seidel 1979). This curve should be useful for obtaining estimates of crown closure from basal area which is more easily measured.

Residual Stand Density and Regeneration

In the Douglas-fir type, overstory basal area, crown closure, and residual trees per acre all showed significant positive correlations to stocking and density of regeneration (tables 6 and 7); in the mixed conifer type, only residual trees per acre was significantly correlated with regeneration (all species combined).

The relationship of greater stocking of 3-year-old and older natural reproduction to the number of overstory trees as density increases is illustrated in figure 4. The equation for the Douglas-fir type is a better predictor of stocking, accounting for 57 percent of the variation in stocking, compared with 34 percent for the mixed conifer equation. Because of the considerable amount of unexplained variation, these curves are not accurate enough for precise estimates of expected regeneration, but they do give some insight into the minimum number of overstory trees needed to obtain adequate stocking. Because of the abundant natural regeneration in the Douglas-fir type, the residual overstory required is much less than in the mixed conifer type where regeneration is not as plentiful. If, for example, 40-percent stocking of milacre plots is considered satisfactory, then 6 to 8 trees per acre in the Douglas-fir type compared with about 25 trees per acre in the mixed conifer type should result in adequate stocking on most units.

Prediction Equations

Reliable equations to assess the potential for regeneration of cutting units before harvest would be useful. To derive such equations, I used only variables that remain unchanged or nearly so over time or that can be adjusted to preharvest values. Thus, variables such as grasses, forbs, and shrubs that tend to increase after harvest were excluded. The variables used were elevation, aspect, slope, slash, degree of burn, basal area, crown closure, number of overstory trees per acre, and average diameter. The amount of slash and degree of burn do not remain completely unchanged over time, but the change is negligible within the timespan of this study. Basal area, trees per acre, and average diameter were adjusted to values immediately after the seed cut by adding data from dead and down trees.

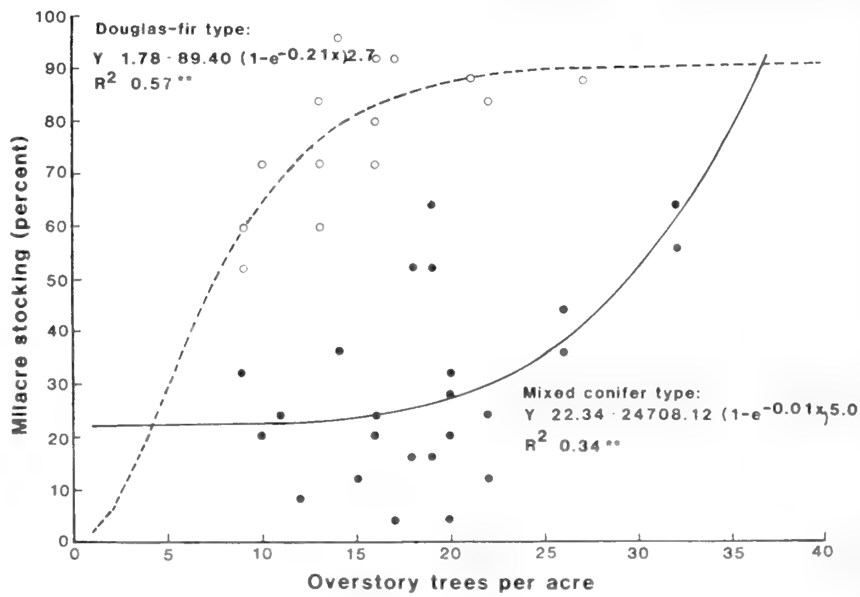

Figure 4.—Relationship between overstory trees per acre and milacre stocking of 3-year-old and older natural regeneration in the Douglas-fir and mixed conifer types in the Cascade Range of Washington; ** means significant at the 1-percent probability level.

In the Douglas-fir type, the equation predicting milacre stocking of 3-year-old and older natural regeneration accounted for 75 percent of the variation with only two variables (crown closure and slash) (table 8 in the appendix). The sign (+ or -) of terms appearing in these equations does not always agree with the sign associated with the correlation coefficients but depends on the particular combination of variables in any equation; for example, basal area appears as a negative term when crown closure is already in the equation but as a positive term when entered first.

The equations for the mixed conifer type accounted for 39 to 68 percent of the variation in stocking (table 9 in the appendix). In the western larch equation, crown closure appeared as a negative term (as in table 6), indicating that the establishment of the shade-intolerant larch was reduced by a heavier overstory in contrast to more shade-tolerant species, such as grand fir, which were favored by greater stand densities.

Because of the considerable amount of unexplained variation associated with these equations and because they were not tested on an independent set of data, they should not be considered accurate predictors of expected regeneration after shelterwood cutting but only crude estimates of possible stocking. The best use of these equations may be to rank proposed shelterwood units on their potential for the establishment of natural regeneration in order to assign supplemental planting.

Influence of Planted Seedlings

Planted seedlings assume greater importance in units where there are fewer natural seedlings. Thus, in the Douglas-fir type where the prolific natural regeneration resulted in all units being well stocked (over 75 percent), planting after the seed cut is unnecesssary. On the other hand, in the mixed conifer type, planting did contribute to satisfactory stocking on some units because of uniform distribution. For example, if a 40-percent stocking of milacre quadrats is considered satisfactory, then planting increased stocking above this level on 19 percent of the units in the mixed conifer type.

The need for planting depends on the forest type or plant community. The best use of planting immediately after the seed cut is in shelterwood units in the mixed conifer type where residual stand density is much below 25 trees per acre or where aggressive understory vegetation could quickly occupy the seedbed. In the Douglas-fir type, the most efficient use of planting is to fill in any holes in the regeneration resulting from removal of the residual overstory.

Overstory Mortality

Mortality of the residual overstory after the seed cut was about three times greater in the mixed conifer type than in the Douglas-fir type. In the mixed conifer type, about 11 percent of the overstory was lost—an average of 1.3 trees per acre blown down and 0.8 tree per acre standing dead. In the Douglas-fir type, about 4 percent of the trees were lost—0.5 tree per acre to windthrow and 0.1 per acre standing dead.

Using the shelterwood system in unmanaged old-growth stands can result in problems with blowdown because trees growing at high densities have not developed the windfirmness needed to resist strong winds after heavy partial cuts. The risk of blowdown can be reduced by leaving dominant or codominant, full-crowned trees that are the most windfirm and also the best seed producers (Gordon 1973). In addition, using guidelines for locating cutting boundaries and for identifying topographic situations where the risk of blowdown is high can decrease the mortality from windthrow. Alexander (1964) prepared such guidelines for spruce-fir forests in Colorado which may be useful in the mixed conifer forests at high elevations in Oregon and Washington.

Conclusions and Recommendations

Results of this survey show that, in the Douglas-fir type, the use of the shelterwood system resulted in satisfactory natural regeneration in all units. In the mixed conifer type, natural regeneration was not as abundant, but the combination of advance reproduction, natural regeneration, and planted seedlings resulted in adequate stocking on about three-fourths of the units. Understocking in this type appeared to be related to at least one of the following factors: nonuniform overstory, lack of advance reproduction, and high elevation.

The shelterwood system should be used only in stands where the risk of excessive blowdown is not extreme and where the stand contains enough healthy dominant and codominant trees to provide a residual overstory spaced uniformly over the area. In such stands, a residual overstory of 6 to 8 trees per acre in the Douglas-fir type and about 25 trees per acre in the mixed conifer type is recommended as sufficient for adequate natural regeneration. Adjustments to residual overstory density can be made for various aspects, slopes, or elevations by use of the prediction equations. These equations provide only very rough estimates of expected stocking and are probably best used to obtain a ranking of potential shelterwood units for natural regeneration rather than an accurate estimate.

Advance reproduction that is sufficiently vigorous to respond to release can be an important component of regeneration in the mixed conifer type, especially in areas where animal damage could be a problem. Saving the advance reproduction requires skillful application of logging techniques designed to preserve the established regeneration, such as those suggested by Gottfried and Jones (1975), and good coordination between timber and fuels management staffs.

Planting after the seed cut is generally not needed in the Douglas-fir type because abundant natural regeneration is quickly established. Planting is most useful here as a supplemental practice to replace natural regeneration destroyed or damaged during the final overstory removal. In the mixed conifer type, shelterwood units should be planted only if residual stand density is not sufficient to obtain natural regeneration or if seedbeds are expected to be invaded quickly by grasses, forbs, or shrubs. If natural regeneration has not resulted in adequate stocking after 3 or 4 years in unplanted units, the residual overstory should be removed and units planted except in frost pockets where seedlings will not survive or grow without the thermal protection of some overstory.

Common and Scientific Names of Plants [5]

Trees:

Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco
Engelmann spruce	*Picea engelmannii* Parry ex Engelm.
Grand fir	*Abies grandis* (Dougl. ex D. Don) Lindl.
Lodgepole pine	*Pinus contorta* Dougl. ex Loud.
Mountain hemlock	*Tsuga mertensiana* (Bong.) Carr.
Pacific silver fir	*Abies amabilis* Dougl. ex Forbes
Ponderosa pine	*Pinus ponderosa* Dougl. ex Laws.
Vine maple	*Acer circinatum* Pursh
Western hemlock	*Tsuga heterophylla* (Raf.) Sarg.
Western larch	*Larix occidentalis* Nutt.
Western redcedar	*Thuja plicata* Donn ex D. Don
Western white pine	*Pinus monticola* Dougl. ex D. Don

Shrubs:

Baldhip rose	*Rosa gymnocarpa* Nutt.
Bearberry	*Arctostaphylos uva-ursi* (L.) Spreng.
Big huckleberry	*Vaccinium membranaceum* Dougl. ex Hook.
Boxwood	*Pachistima myrsinites* (Pursh) Raf.
Common snowberry	*Symphoricarpos albus* (L.) Blake
Prince's pine	*Chimaphila umbellata* (L.) Bart.
Shinyleaf spirea	*Spiraea betulifolia* Pall.
Thimbleberry	*Rubus parviflorus* Nutt.

Forbs:

American vetch	*Vicia americana* Muhl. ex Willd.
Beargrass	*Xerophyllum tenax* (Pursh) Nutt.
Rattlesnake plantain	*Goodyera oblongifolia* Raf.
Sky lupine	*Lupinus nanus* Dougl.
Twinflower	*Linnaea borealis* L.
Woollyweed	*Hieracium scouleri* Hook.

Grasses:

Idaho fescue	*Festuca idahoensis* Elmer
Pinegrass	*Calamagrostis rubescens* Buckl.

[5] Sources for nomenclature: trees (Little 1979); shrubs, forbs, and grasses (Garrison and others 1976).

Metric Equivalents

1 acre = 0.405 hectare
1 foot = 0.3048 meter
1 inch = 2.54 centimeters
1 mile = 1.61 kilometers
1 square foot = 0.0929 square meter
1 square foot/acre = 0.2296 square meter/hectare
1 tree/acre = 2.47 trees/hectare

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Appendix

Independent (X) variables used in regression analyses:

1. **Elevation.**—The average elevation of the plot to the nearest 10 feet as measured with an altimeter.
2. **Aspect.**—One of eight compass points measured on each subplot. The method proposed by Day and Monk (1974) was used to code the aspect, and the following values were assigned to compass directions: N - 14; NE - 15; E - 11; SE - 7; S - 3; SW - 2; W - 6; NW - 10. Average coded value of the 25 subplots was used in analyses.
3. **Slope.**—Percentage slope of each subplot was measured with a clinometer and coded as follows: 0-9 percent, 0; 10-19 percent, 1; 20-29 percent, 2; 30-39 percent, 3; etc. Average coded value of subplots was used.
4. **Mineral soil.**—The percentage of each subplot containing mineral soil was estimated, coded in the same way as slope values, and averaged.
5. **Litter.**—The percentage of each subplot covered with litter was estimated, coded in the same way as slope values, and averaged.
6. **Slash.**—The percentage of each subplot covered with slash was estimated, coded in the same way as slope values, and averaged.
7. **Degree of burn.**—Estimated on each subplot and coded as: none, 0; light, 1; medium, 2; heavy, 3. Averaged coded value was used in analyses. Degree of burn is defined as: None—no visible effect of fire; light—fire charred the surface of the forest floor but did not remove all the litter layer; medium—fire removed all the litter layer and some of the duff; heavy—fire removed all the litter and duff and imparted a color to the mineral soil.
8. **Forbs.**—The percentage of each subplot covered with forbs was estimated, coded in the same way as slope values, and averaged.
9. **Shrubs.**—The percentage of each subplot covered with shrubs was estimated, coded in the same way as slope values, and averaged.
10. **Grasses and sedges.**—The percentage of each subplot covered with grasses and sedges was estimated, coded in the same way as slope values, and averaged.
11. **Basal area.**—The overstory basal area at each subplot was measured with a 10-factor angle gage and averaged for use in analyses.
12. **Crown closure.**—The overstory crown closure was measured with a spherical densiometer at each subplot by Strickler's (1959) method. Average value of the 25 subplots was used in analyses.
13. **Overstory trees per acre.**—The numbers of standing overstory trees (living and dead) and blown down trees were recorded on 0.0785-acre subplots at each of the 25 sample points, averaged, and converted to a per-acre basis.
14. **Overstory average diameter.**—The diameters at breast height of living and dead standing trees and blown down trees on each 0.0785-acre subplot were measured to the nearest inch and averaged.
15. **Animal damage.**—The presence or absence of damage such as browsing or trampling by animals other than gophers (primarily deer, elk, or cattle) was recorded for each subplot. The percentage of subplots showing such damage was used in the analyses.
16. **Gopher activity.**—The presence or absence of gopher activity as indicated by mounds was recorded for each subplot. The percentage of subplots showing such activity was used in the analyses.
17. **Age of unit.**—The number of years since the seed cut was made was recorded for each unit.

Table 6—Significant correlation coefficients (r) between environmental variables and stocking percent of regeneration on shelterwood units in 2 timber types in the Cascade Range of Washington 1/

Species or origin	Aspect	Slope	Elevation	Mineral soil	Litter	Slash	Burn 2/	Forbs	Shrubs	Grass	Basal area	Crown closure	Residual trees per acre	Quadratic mean diameter	Animal damage	Gopher damage	Age of unit
Douglas-fir type:																	
All regeneration	-	+	+	+	-	+	+	-	+	-0.95**	+	+	+	-	-0.69**	-	-
All natural regeneration	-	-	-	+	+	-	+	-	+	-.79**	+	0.53*	+	-	-.56*	+	-
All postharvest regeneration	-	-	+	+	+	-	+	-	+	-.76**	+	.46	+	-	-.53*	+	-
Natural postharvest	-	-	-	+	+	-	+	-	+	-.73**	+	.49	+	-	-.52*	+	-
3 years old and older	-	-0.47	-	+	0.45	-	-	+	+	-.59*	0.53*	.74**	0.63*	+	-	+	-
All grand fir	-	-.48	-	+	+	+	-	0.53*	0.69**	-	.79**	.77**	.65*	-	-	+	-0.63*
All Douglas-fir	-	-	+	+	+	-	-	-	-	-.84**	+	+	+	-	-.47	-	-
Mixed conifer type:																	
All regeneration	+	+	-			+	-	-.39*	.37	-	+	-	.50**	-0.46*	+	-	+
All natural regeneration	+	+	-			+	-	-.33	+	-	+	+	.50**	-.55**	+	-	+
All postharvest regeneration	+	-	-			+	-	-	+	+	-	-	.53**	-.35	+	-	+
Natural postharvest	+	-	-			+	-	-	+	+	-	+	.56**	-.47*	+	+	+
3 years old and older	+	-	-0.35			+	-	-	+	+	-	-	.51**	-.34	-.34	+	+
1 and 2 years old	+	-	-			-	+	-	+	+	-	+	.33	-.50**	-.40*	+	+
All grand fir	+	-	-.34			0.33	+	-	.39*	-	-	+	.49**	-.60**	+	-	.39*
Postharvest grand fir	+	+	-.47*			+	+	-	+	+	+	+	.65**	-.43*	+	+	+
All Douglas-fir	-	-	-.55**			+	0.34	+	+	.33	-	+	.54**	-.33	.37	+	+
Postharvest Douglas-fir	-	-	-.53**			+	.34	+	+	.33	-	+	.51**	-	+	+	-
All ponderosa pine	-0.42*	+	-.36			-	-	.33	-	.50**	-	+	+	-	-	+	-
All larch	+	-	+			-	-	-.40*	-	-	-	-.54**	-	+	-	-	+
All spruce	.37	-	.35			-	-	-.47*	-	-	-	-.59**	-	-	+	-	.53**
All white pine	+	+	-			+	+	-	+	-	-	-	+	-.37	.40*	-	.81**

1/ Correlation coefficients with no asterisk are significant at the 10-percent probability level; 1 asterisk, 5-percent level; 2 asterisks, 1-percent level. Plus and minus signs indicate a nonsignificant positive or negative correlation.

2/ Pile and burn.

Table 7—Significant correlation coefficients (r) between environmental variables and density of regeneration on shelterwood units in 2 timber types in the Cascade Range of Washington 1/

Species or origin	Aspect	Slope	Elevation	Mineral soil	Litter	Slash	Burn 2/	Forbs	Shrubs	Grass	Basal area	Crown closure	Residual trees per acre	Quadratic mean diameter	Animal damage	Gopher damage	Age of unit
Douglas-fir type:																	
All regeneration	-0.47	-	-	-	0.53*	-	-	-	+	-0.46	+	0.54*	0.57*	-	-	-	-
All natural regeneration	-.48	-	-	-	.53*	-	-	+	+	-	+	.53*	.56*	-	-	-	-
All postharvest regeneration	-.48	-0.45	-	-	.53*	-	-	-	+	-.46	+	.53*	.57*	-	-	-	-
Natural postharvest	-.48	-.45	-	-	.54*	-	-	+	+	-	+	.53*	.56*	-	-	-	-
3 years old and older	-.60*	-.55*	-	-	+	+	-	+	+	-	0.61*	.65*	.71**	-	-	+	-0.57*
All grand fir	-.65*	-.47	-	-	+	+	-	0.49	0.54*	-	.70**	.70**	.78**	-	-	+	-.49
All Douglas-fir	-	-	+	+	+	-	-	-	-	-.49	+	+	+	+	-	-	-
Mixed conifer type:																	
All regeneration	+	+	-			+	-	-	+	-	-	-	.42*	-0.56**	+	-	+
All natural regeneration	+	+	-			+	-	-	+	-	-	+	.43*	-.59**	+	-	+
All postharvest regeneration	+	-	-0.36			-	-	-	+	+	-	-	.41*	-.50**	0.42*	+	+
Natural postharvest	+	+	-.37			+	-	-	+	+	-	-	.43*	-.55**	.42*	+	+
3 years old and older	+	+	-.34			+	-	-	+	+	-	-	.39*	-.48*	.35	+	+
1 and 2 years old	+	-	-.32			+	+	-	+	+	-	+	.37	-.52**	.42*	+	+
All grand fir	+	+	-			0.33	+	-	+	-	-	+	.40*	-.57**	+	-	.63**
Postharvest fir	+	+	-.42*			.36	+	+	+	+	-	.38*	.72**	-.43*	+	+	-
All Douglas-fir	-	-	-.45*			-	+	.35	+	.36	+	.52**	.50**	-.34	+	+	+
Postharvest Douglas-fir	-	-	-.42*			-	+	.39*	+	.38*	+	.53**	.51**	-	+	+	-
All ponderosa pine	-.43*	+	-.33			-	-	+	-	.45*	-	+	+	-	+	+	-
All larch	+	-	.33			-	-	-.37	-	-	+	-.47	-	+	-	-	-
All spruce	.36	-	+			-	-	-.35	-	-	-	-.62	-	+	+	-	.51**
All white pine	+	+	+			+	-	-	+	-	-	-	+	-	+	-	+

1/ Correlation coefficients with no asterisk are significant at the 10-percent probability level; 1 asterisk, 5-percent level; 2 asterisks, 1-percent level. Plus and minus signs indicate a nonsignificant positive or negative correlation.

2/ Pile and burn.

Table 8—Prediction equations for milacre stocking on shelterwood units in a Douglas-fir type in the Cascade Range of Washington

Dependent variable	Equation	Variation explained, R^2	Standard error of estimate, $S_{y \cdot x}$
		-------Percent--------	
1- and 2-year-old seedlings	= -5.63 + 8.50 (slash) + 4.50 (crown closure) -1.79 (basal area)	0.55	9.5
3-year-old and older seedlings	= 57.63 + .90 (crown closure) - 9.08 (slash)	.75	7.4
All natural regeneration	= -26.52 + 1.83 (crown closure) - 0.42 (basal area) + 0.022 (elevation) + 21.72 (burn)	.64	9.02
All regeneration	= -425.73 + 1.88 (crown closure) + 0.083 (elevation) - 5.16 (slope) + 9.14 (age) + 3.56 ($\bar{x}$ diameter) + 8.58 (slash)	.66	8.2
All grand fir	= 183.63 + 1.59 (basal area) - 19.37 (slash) -2.82 ($\bar{x}$ diameter) - 6.25 (trees/acre) - 2.88 (aspect)	.83	14.8
All Douglas-fir	= -86.74 + 3.03 (crown closure) - 0.81 (basal area) + 0.034 (elevation)	1/ .44	19.7

1/ Not significant.

Table 9—Prediction equations for milacre stocking on shelterwood units in a mixed conifer type in the Cascade Range of Washington

Dependent variable	Equation	Variation explained, R^2	Standard error of estimate, $S_{y \cdot x}$
		-------Percent--------	
1- and 2-year-old seedlings	= 19.77 - 1.92 ($\bar{x}$ diameter) + 5.27 (age) + 0.82 (trees/acre) - 0.82 (aspect)	0.39	14.3
3-year-old and older seedlings	= -44.13 + 2.15 (trees/acre) + 8.93 (age) + 8.41 (slope) - 0.006 (elevation)	.60	12.2
All natural regeneration	= -29.32 - 2.74 ($\bar{x}$ diameter) + 0.69 (basal area) + 10.43 (age) + 1.80 (trees/acre) + 15.70 (slope)	.68	13.9
Natural postharvest	= -43.87 + 2.50 (trees/acre) + 9.76 (age) - 1.39 ($\bar{x}$ diameter) + 9.16 (slope)	.61	14.8
All regeneration	= -40.22 + 2.02 (trees/acre) + 10.79 (age) + 15.49 (slope) - 1.72 ($\bar{x}$ diameter) + 0.45 (basal area)	.68	12.5
All grand fir	= 20.22 - 1.11 ($\bar{x}$ diameter) + 1.19 (trees/acre) + 8.21 (slope)	.53	14.0
Postharvest grand fir	= 22.18 + 1.13 (trees/acre) - 0.007 (elevation) + 4.43 (slash)	.51	10.7
All Douglas-fir	= 46.54 - 0.012 (elevation) + 1.15 (trees/acre) + 29.24 (burn)	.49	14.9
All ponderosa pine	= 33.22 - 0.67 (aspect) - 0.85 ($\bar{x}$ diameter) - 4.80 (slash) + 3.71 (slope)	.46	6.6
All larch	= 51.93 - 1.23 (crown closure) - 38.75 (burn) - 5.31 (slope)	.52	10.1

Seidel, K. W. Regeneration in mixed conifer and Douglas-fir shelterwood cuttings in the Cascade Range of Washington. Res. Pap. PNW-314. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1983.** 17 p.

A survey of shelterwood cuttings in mixed conifer and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) forests in the Cascade Range in Washington showed that, on the average, shelterwood units were adequately stocked with a mixture of advance, natural postharvest, and planted reproduction of a number of species. Shelterwood cuttings in the Douglas-fir type had abundant regeneration, whereas those in the mixed conifer type had generally adequate stocking but fewer seedlings. Much of the understocking appeared to be related to a nonuniform overstory, lack of advance reproduction, or high elevation.

Keywords: Shelterwood cutting method, regeneration (stand), regeneration (natural), regeneration (artificial), Cascade Range—Washington, Washington (Cascade Range).

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